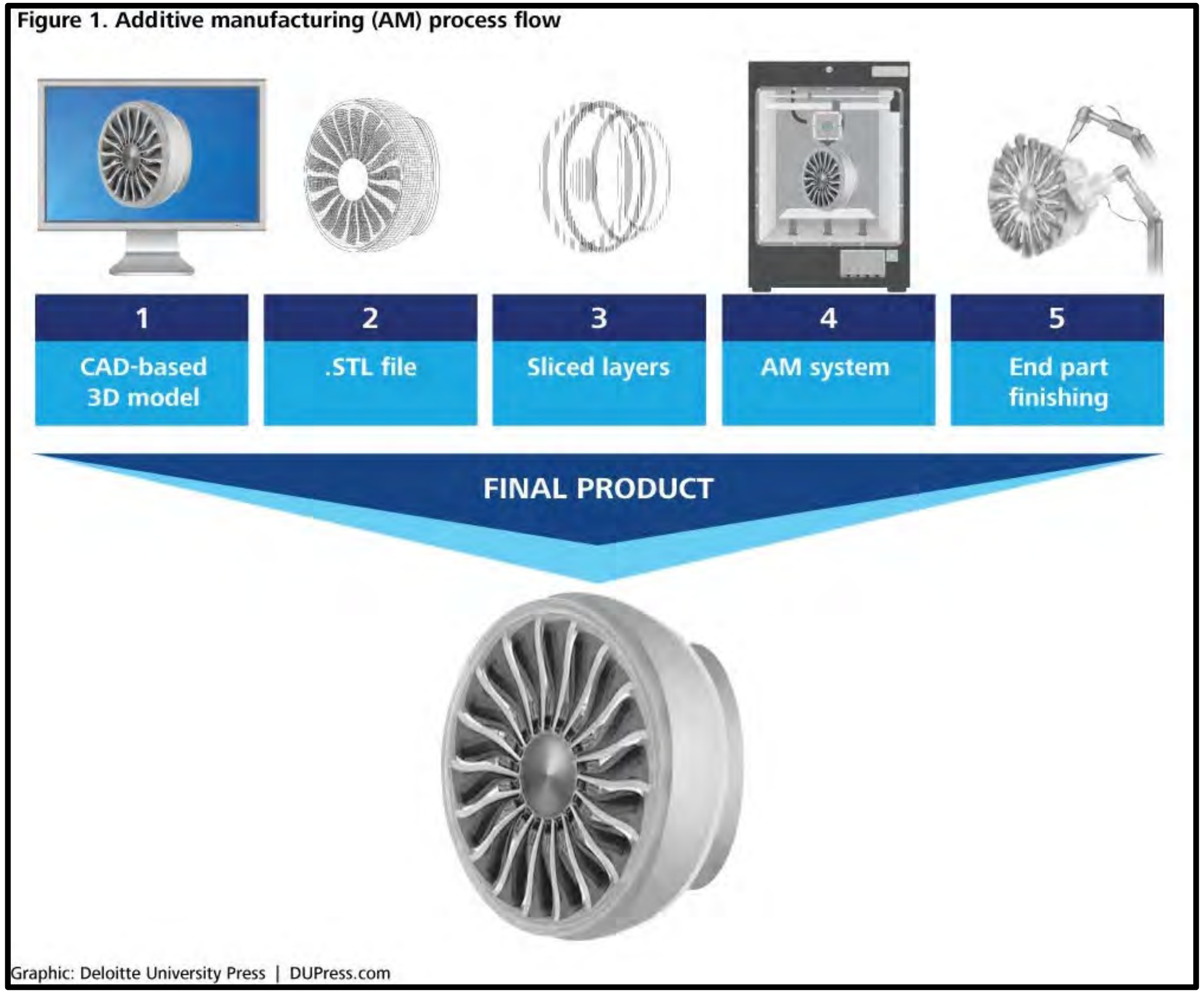
Additive Manufacturing

Special Operations Forces Capability Production at the Point of Need

Agenda

- Additive Manufacturing-Definition
- Benefits
- Challenges
- AM is a Growth Industry
- Non-competitive Collaboration
- AM in DoD
- Future for SOF

What is Additive Manufacturing



https://www2.deloitte.com/content/dam/insights/us/articles/additive-manufacturing-3d-opportunity-in-aerospace/DUP_706_Figure1_AM_process_flow.jpg

Benefits of AM

- **Improved design options (lattice, truss and cellular design)**
- **Design for AM (Part count reduction)**
- **Customization**
- **AM Production Benefits**

Design Options

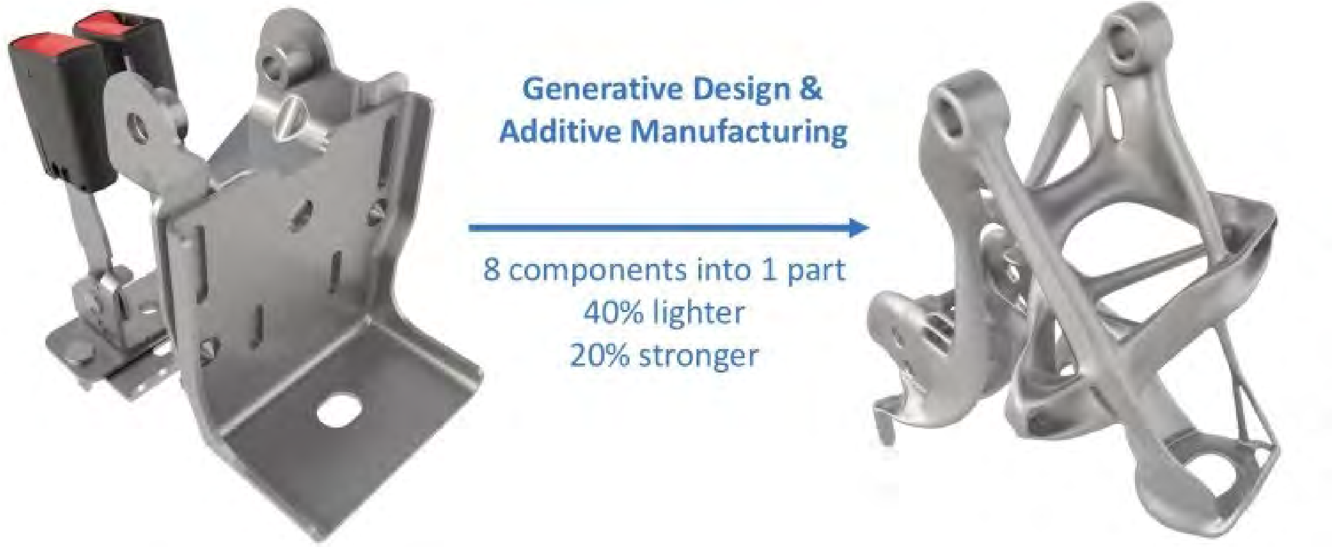
http://www.prototypetoday.com/images/index/k2/akec%203d%20act%20hip%20system%20with%20cfda%20approval.jpg

http://www.fit-america.com/img/products/adme.jpg

http://2biy4djn37s2xoe622u8h9g1.wpengine.netdna-cdn.com/wp-content/uploads/2017/01/aec224c21d159255_org.jpg

Design for AM

https://www.renishaw.com/media/img/en/a0923141ed2741c49259b64252fc09f4.png



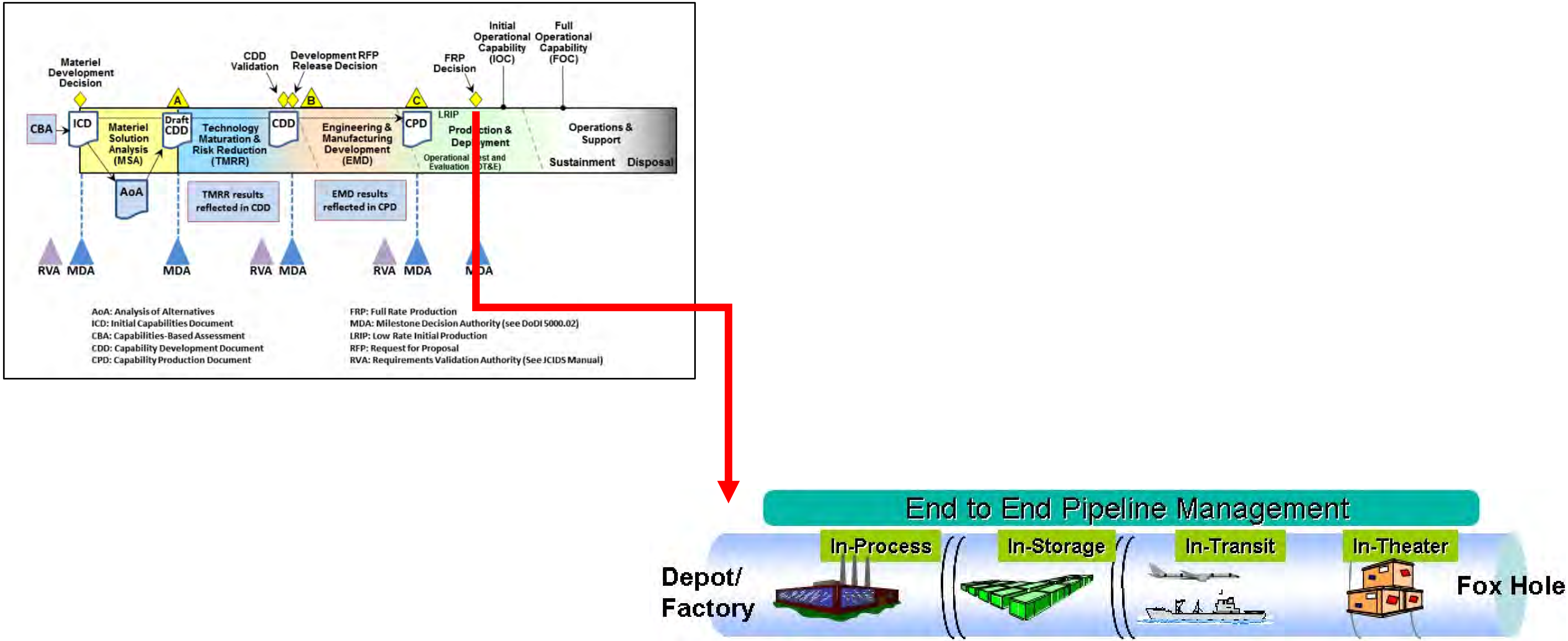
https://i1.wp.com/www.blogdot.tv/wp-content/uploads/2018/05/gm-and-autodesk-using-additive-manufacturing-for-lighter-vehicles.jpg

Customization

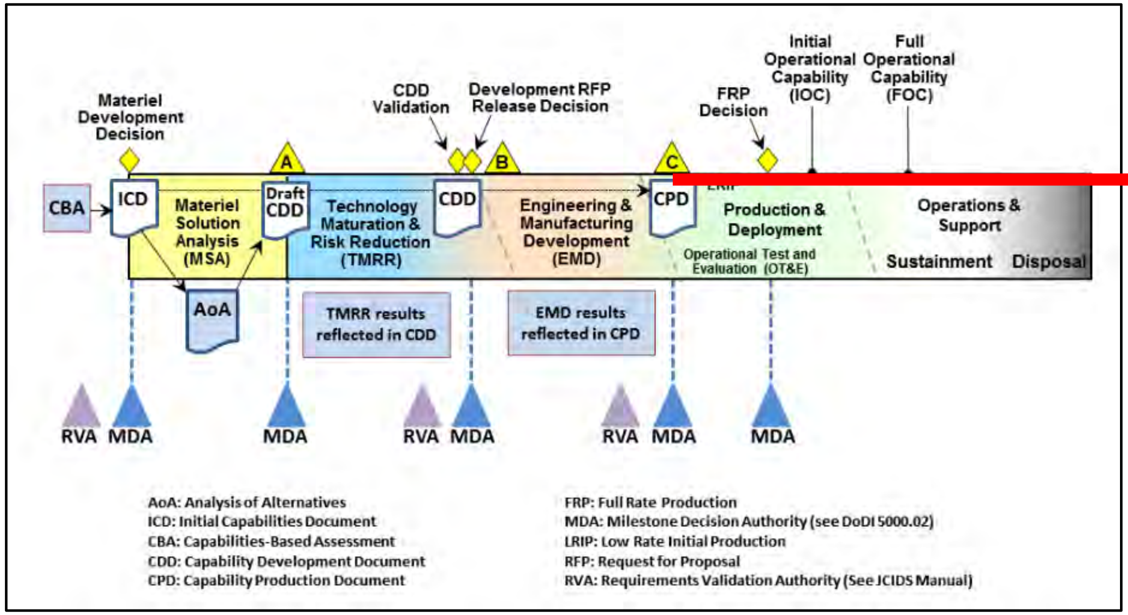
https://cdn-images-1.medium.com/max/1600/1*jsJzs8wj0hUcviHsZpsKOg.jpeg

https://damassets.autodesk.net/content/dam/autodesk/www/solutions/additive-manufacturing/custom-tailored-components-image-thumb-600x300.jpg

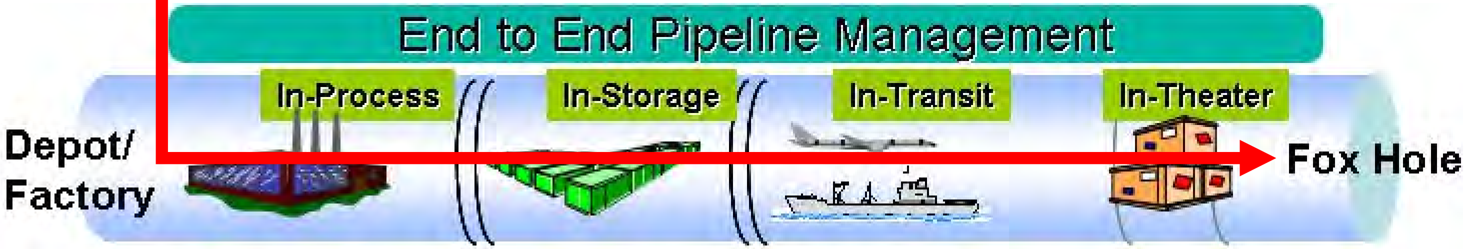
Traditional Production



AM Production Benefits



- Distributed production
- Elimination of tooling
- Agile manufacturing and reduced lead time
- Closes gap from developer to consumer
- Inventory Reduction and parts consolidation
- Sustainability and waste reduction



Wolhers Report 2018

Successful AM Cases—GE Aviation

- **GE used AM part consolidation for *CT7 helicopter engine***
- **Engine redesign resulted in 40% engine made with AM parts**
- **Consolidated 900 parts into 16**
- **Weight reduction by 35%**
- **Cost reduction 40%**

- **Combustion chamber inside engine:**
- **Typically 5-6 engineers takes a year to design/test;**
- **Using AM one engineer redesigned/tested in six months**
- **Reduced weight by 30%**

Wolhers Report 2018

Successful AM Cases—GE Aviation

- **GE used AM part consolidation for *Advanced Turboprop engine***
- **January 2018 engine new design**
- **Consolidated <u>855 parts into 12</u>**
- **Weight reduction by <u>100 lbs.</u>**
- **<u>Reduced fuel consumption</u> by 20%**
- **Gained 10% <u>more power</u>**
- **Resulted in <u>reduced maintenance, overhead</u> with documentation, inspection, production planning/control**
- **Reduced assembly line "footprint"**

Wolhers Report 2018 https://youtu.be/BnBMN0zgB10?t=154

Challenges of AM

- **Operating <u>cost</u>**
  - **Price of AM machines**
  - **Cost of build materials**
- **Machine-to-machine <u>variability</u>**
  - **Challenge in traditional manufacturing**
  - **Increased challenge distributed (austere)**
- **<u>Quality control</u>**
- **<u>Intellectual property infringement</u>**
- **<u>Cyber Vulnerabilities</u>**
- **<u>Culture</u>**

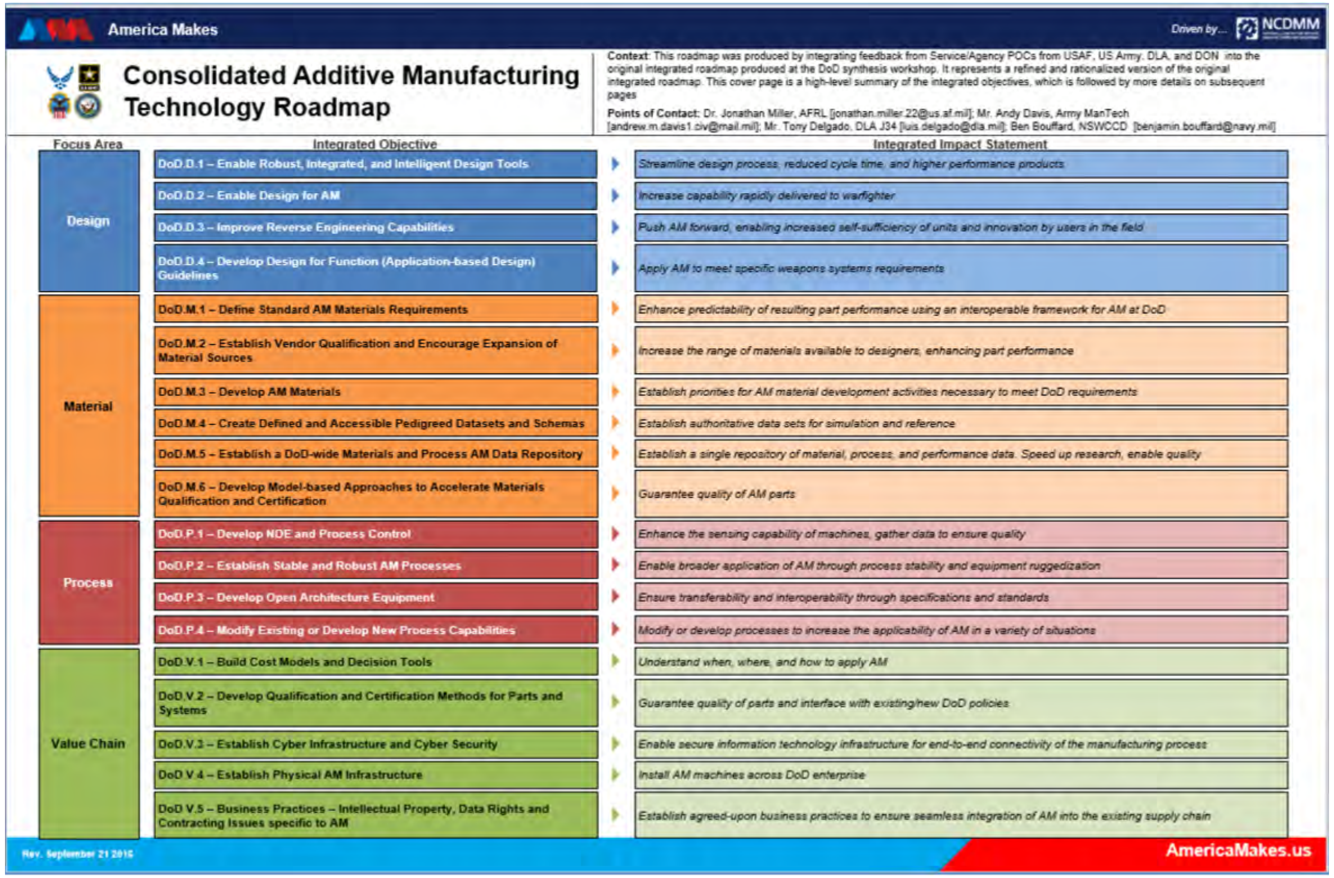
Wolhers Report 2018

AM is a Growth Industry

- **Industry growth continues to grow**
  - **Last <u>29 years of worldwide revenues</u> AM products/services <u>grew 26.6%</u> each year (excludes company internal investment)**
  - **<u>2017</u> industry grew <u>21%</u> to <u>$7.336B</u> worldwide**
    - ***Product*-AM systems, upgrades, materials and aftermarket products**
    - ***Services*-parts produced by AM service providers, maintenance contracts, training, seminars etc.**

America Makes

- Leading collaborator to innovate and accelerate AM and 3DP to increase our nation's global manufacturing competitiveness
- <u>Public Private Partnership</u>
  - $65M gov't investment
  - $68M private sector investment
- <u>Non-competitive collaboration</u>
- Membership from industry, academia, gov't
- In 2017, 200+ member organizations



America Makes — Driven by... NCDMM

Consolidated Additive Manufacturing Technology Roadmap

Context: This roadmap was produced by integrating feedback from Service/Agency POCs from USAF, US Army, DLA, and DON into the original integrated roadmap produced at the DoD synthesis workshop. It represents a refined and rationalized version of the original integrated roadmap. This cover page is a high-level summary of the integrated objectives, which is followed by more details on subsequent pages

Points of Contact: Dr. Jonathan Miller, AFRL [jonathan.miller.22@us.af.mil]; Mr. Andy Davis, Army ManTech [andrew.m.davis1.civ@mail.mil]; Mr. Tony Delgado, DLA J34 [luis.delgado@dla.mil]; Ben Bouffard, NSWCCD [benjamin.bouffard@navy.mil]

Focus Area	Integrated Objective	Integrated Impact Statement
Design	DoD.D.1 – Enable Robust, Integrated, and Intelligent Design Tools	Streamline design process, reduced cycle time, and higher performance products
	DoD.D.2 – Enable Design for AM	Increase capability rapidly delivered to warfighter
	DoD.D.3 – Improve Reverse Engineering Capabilities	Push AM forward, enabling increased self-sufficiency of units and innovation by users in the field
	DoD.D.4 – Develop Design for Function (Application-based Design) Guidelines	Apply AM to meet specific weapons systems requirements
Material	DoD.M.1 – Define Standard AM Materials Requirements	Enhance predictability of resulting part performance using an interoperable framework for AM at DoD
	DoD.M.2 – Establish Vendor Qualification and Encourage Expansion of Material Sources	Increase the range of materials available to designers, enhancing part performance
	DoD.M.3 – Develop AM Materials	Establish priorities for AM material development activities necessary to meet DoD requirements
	DoD.M.4 – Create Defined and Accessible Pedigreed Datasets and Schemas	Establish authoritative data sets for simulation and reference
	DoD.M.5 – Establish a DoD-wide Materials and Process AM Data Repository	Establish a single repository of material, process, and performance data. Speed up research, enable quality
	DoD.M.6 – Develop Model-based Approaches to Accelerate Materials Qualification and Certification	Guarantee quality of AM parts
Process	DoD.P.1 – Develop NDE and Process Control	Enhance the sensing capability of machines, gather data to ensure quality
	DoD.P.2 – Establish Stable and Robust AM Processes	Enable broader application of AM through process stability and equipment ruggedization
	DoD.P.3 – Develop Open Architecture Equipment	Ensure transferability and interoperability through specifications and standards
	DoD.P.4 – Modify Existing or Develop New Process Capabilities	Modify or develop processes to increase the applicability of AM in a variety of situations
Value Chain	DoD.V.1 – Build Cost Models and Decision Tools	Understand when, where, and how to apply AM
	DoD.V.2 – Develop Qualification and Certification Methods for Parts and Systems	Guarantee quality of parts and interface with existing/new DoD policies
	DoD.V.3 – Establish Cyber Infrastructure and Cyber Security	Enable secure information technology infrastructure for end-to-end connectivity of the manufacturing process
	DoD V.4 – Establish Physical AM Infrastructure	Install AM machines across DoD enterprise
	DoD V.5 – Business Practices – Intellectual Property, Data Rights and Contracting Issues specific to AM	Establish agreed-upon business practices to ensure seamless integration of AM into the existing supply chain

Rev. September 21 2016 — AmericaMakes.us

- <u>Created DoD AM Roadmap</u> collaboration with USA, USAF, DON, DLA

https://youtu.be/EWY7x6yGqzQ

https://www.americamakes.us/our_work/technology-roadmap/ https://youtu.be/HZk6j9SwGxY

Demonstrated Capability Production

- US Army Manufacturing Technology (ManTech), US Army Research, Development and Engineering Command (RDECOM), and national 3D printing accelerator America Makes printed a grenade launcher
- 6 months
- Two RDECOM R&D centers – the US Army Research Lab (ARL) and the US Army Edgewood Chemical and Biological Center (ECBC) participated in manufacturing the munition
- **First successfully test fired 3DP weapon**

The additively-manufactured RAMBO system includes an NSRDEC-designed standalone kit with printed adjustable buttstock, mounts, grips and other modifications—modifications made possible by the quick turnaround time afforded by 3D printing.

These M781 components were 3D-printed during a six-month collaborative effort that involved RDECOM, ManTech and America Makes, the national accelerator for additive manufacturing and 3D printing. They cost tens of thousands of dollars less than identical components created with standard production methods.

https://3dprint.com/167567/3d-printed-grenade-launcher/

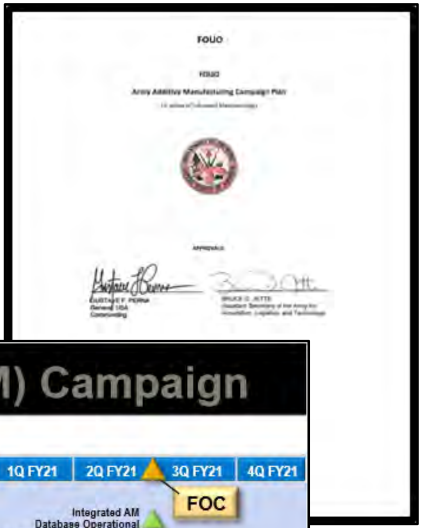
Current AM in DoD

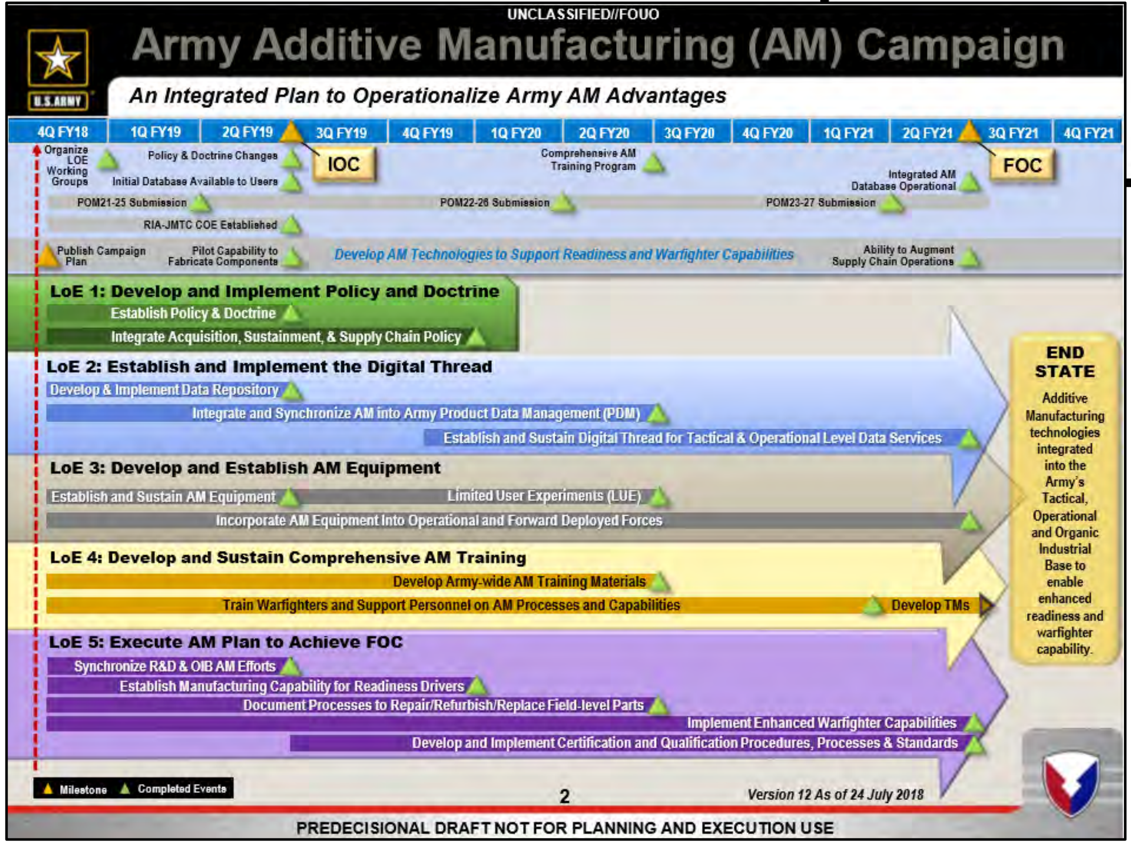
- **Supply Chain/Readiness**
  - **AM Center of Excellence (Rock Island Arsenal)**
  - ***Rapid Fabrication via Additive manufacturing on the Battlefield* (R-FAB) / *Digital Repository for AM Parts for Tactical & Operational Readiness* (RAPTOR)**

- **Customized service member solutions**
  - **Rapid Equipping Force (REF) Ex Lab**
  - **Mobile Technology & Repair Complex (MTRC)**

AM Center of Excellence

AM Campaign Plan was developed under Secretary of the Army and Army Senior leadership guidance to integrate/synchronize Army AM Capabilities and operationalize AM to increase tactical/operational readiness and enhance warfighting capabilities





- LOE 1: Develop and Implement Coordinated Policy and Doctrine for AM
- LOE 2: Develop and Implement the Digital Thread for AM
- LOE 3: Develop and Establish Equipment for AM
- LOE 4: Develop Comprehensive Training to Support AM
- LOE 5: Execution of the AM Plan to Support Tactical and Operational Environments
  - Enhance Warfighter Capability
  - Increase Tactical and Operational Readiness

Rapid Fabrication via Additive manufacturing on the Battlefield (R-FAB)

- **R-FAB readiness gains through printing battle damage assessment repair (BDAR) and Emergency Repair parts in the field**

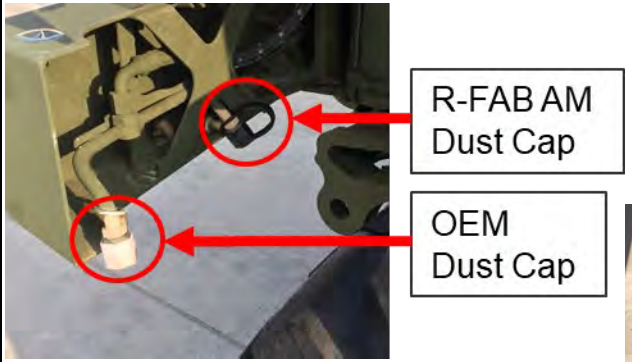
- **Field print temporary parts wait on OEM parts**

- **Test bed to integrate and demonstrate evolving AM technologies; database of files; informs AM CoE**

- **Print capabilities: Variety of parts – from soft rubbers to high strength KEVLAR reinforced Nylon**

R-FAB

3D Print Examples



Digital Repository for AM Parts for Tactical & Operational Readiness (RAPTOR)

- **Soldiers entry to <u>Digital Thread</u>**

- **Easy-to-use interface <u>linking soldier to part</u> – Graphic User Interface (GUI) is intuitive**

- **Multiple part file search options**

- **Developed <u>expeditionary applications</u> – However, <u>scalable</u> from point-of-need <u>to enterprise deployment</u>**

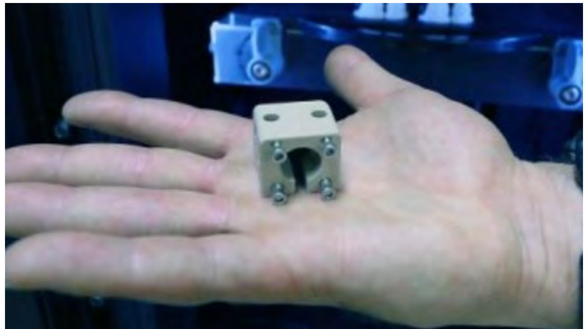
- **Provides Soldier to <u>engineering reach back</u> – Other RDECs within RDECOM – LCMCs, PMs etc –**

Rapid Equipping Force Ex Lab

- Started in 2012
- To connect scientists, engineers and Soldier in deployed locations
- 3D printing and rapid prototyping
- Sewing, machining, electrical
- Located in Afghanistan
- Has communication reach back to technical SMEs
- Deliver goal: 180 days usually <30 days

Expeditionary Capability in Austere Environment

3D Print Examples



https://www.ref.army.mil/Projects

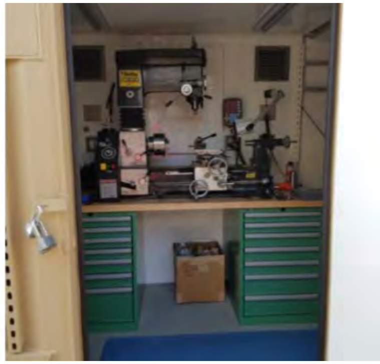
Mobile Technology & Repair Complex (MTRC)

- Responsive point of need engineering support austere or limited support locations
- 2 person team (Engineer/SOF Technician)

- Engineering support
- CAD, 3D printing, documentation, risk management
- Welding, machining, carpentry / electrical
- Kydex & Sewing
- Limited / Weapons / Communications maintenance Support

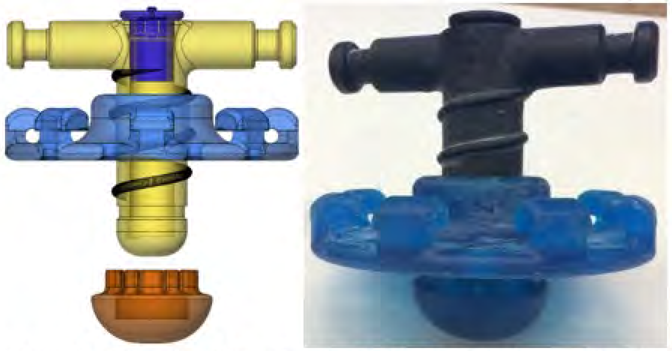
Expeditionary Capability in Austere Environment





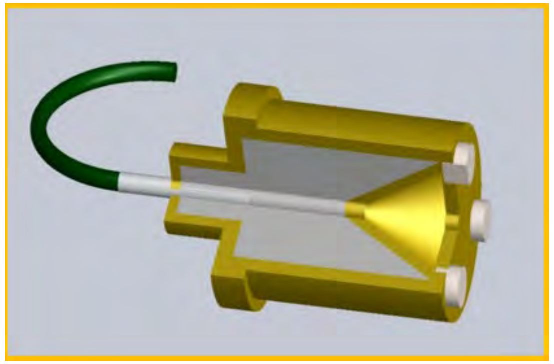
3D Print Examples

Tourniquet



Screw type junctional tourniquet CAD (L), 3D printed assembly (R)

Shape Charge



Analysis

- AM is an evolution in manufacturing—not the revolution yet
- Design for AM has tremendous benefits but still not seeing strong end-item production—GE major success with AM but still rely on traditional manufacture in a controlled environment
- Strong growth and becoming more mainstream technology—cost will continue to drop as tech increases
- DoD is committed
- IP is a large barrier in AM capability development—less in supply chain (can ERO parts) and readiness but still a large issue
- IP policy is a start but needs to be focused on design for AM complete end-item production
- Collaborative relationships offer compounded benefits for AM
    - Within DoD, Army and non-competitive (ex. America Makes)
- Themes among DoD: Digital thread, technical reach-back, collaboration across industry, design for AM

Recommendations for Future AM in SOF

1. **Leverage Army**
   - **IP Policy update—culture of collaboration/design for AM end-item production**
   - **AM CoE—supply chain efficiencies/data repository**
2. **Explore partnership with America Makes**
   - **Collaboration with consortium of AM SMEs for future options**
   - **Explore partnership with AM service provider for low quantity/high complexity builds**
3. **Metals and continuous fiber filament 3D printers are the next evolution from a process/material standpoint—price affordable**
4. **Pursue reach back from remote locations**

Backup

R-FAB HISTORY

DEVCOM

Army Warfighter Assessment FY17 Oct 2016

- Ft Bliss Texas
- One sided expandable shelter
- Four lab graded 3-D Printers utilizing composite material (plastic)
- Basic 3D scanner
- Populate RAPTOR database– digital library storing data files used for fabricating parts

Pacific Pathways 17.3 Aug-Sep 2017

- Hanuman Guardian (Thailand)
- Orient Shield (Japan)
- Expanded workspace using two sided expandable shelter
- Upgraded from lab to industrial grade 3D printers
- Expand on AWA 17 RAPTOR database library of part files

Joint Warfighter Assessment 18.1 May 2018

- Hohenfels Germany
- Upgraded 3D scanner
- Added satellite connectivity for expanded "reach back" capability
- Continue to populate and apply lessons learned for the RAPTOR database

Korea Operational Assessment Aug 2018 - Aug 2019

- Camp Humphreys Korea
- Five 3D printers
- Industrial grade 3D printers with capability to make more robust parts using KEVLAR, Carbon-Fiber infused Nylon, ASA and other high performance polymers
- RAPTOR database is open for Army use

Future versions to incorporate maturing AM technologies (e.g. cold-spray, metal, circuit boards, energetics, etc)

PARTS PRODUCED IN R-FAB BIG WINS AS OF 11 JAN 2019

- 284 total MRAP Dust Caps – 1,472 NMC days saved*
- 206 Explosive Ordnance Disposal (EOD) Training Aids: Enabling continued Soldier training for certification; increasing Soldier readiness
- 4 Crime Investigation Division (CID) Shallow Grave Training Aids - Enabling continued Soldier training for certification; increasing Soldier readiness
- Aviation maintenance shop tooling for the Air Reserve Base (ARB) – 1 produced, tested, and approved; other parts are being requested by this shop as well

*NMC days are cumulative and calculated based on the time OEM parts were ordered and estimated delivery date of OEM parts

PARTS PRODUCED SO FAR IN KOREA OA

- 48 unique parts produced
- 511 total parts produced
- 1,705 NMC days saved

Screw Type Junctional Tourniquet

MTRC TM I-1 BDSC: Joseph Burkart

Who: CJSOTF-I
What: Screw Type Junctional Tourniquet
Where: BDSC
When: 28JUN18
Why: Based on the results of the Junctional Tourniquet evaluation, JT#6C was redesigned. Designed an effective field use Junctional Tourniquet, that is easy to install, stays in place during movement, and completely stops blood flow through the artery. An advantage of the Screw Type Junctional Tourniquet is that it allows the medic to easily stop or start blood flow in order to efficiently identify sources of bleeding. Development of an effective Junctional Tourniquet will help save lives of CJSOTF-I personnel.

Ultrasound showing blood flow (L), no blood flow (R)

Screw type junctional tourniquet CAD

Engineering Approach

- Redesigned JT#6C based on initial test comments
- Curved or 'mushroom' style cap was found to be the most effective at stopping blood flow
- A detent in the screw and flex-tabs on the curved cap allows the cap to snap into place during install
- A flex-tab retention method allows the cap to rotate, which prevents the cap from twisting the skin when turning the screw
- Screw end was curved to use as the contact point in case cap is lost
- Redesigned tabs to better retain D-ring and SOFT-W buckle
- Added holes to route 550 cord to lock handle once tightened
- Added a TXA vial storage to the center of the screw to save space
- Performed verification testing on screw type and next-gen junctional tourniquets, both were success at stopping blood flow
- With proper positioning blood flow was stopped without tightening the SOFT-W windlass, if position was slightly off tightening the windlass stopped blood flow
- Sewed carrying case to fit components
- Provided SOFT-W tourniquet adapter straps and standalone straps

Risk Level: Low

UNCLASSIFIED//FOR OFFICIAL USE ONLY

Screw Type Junctional Tourniquet

MTRC TM I-1 BDSC: Joseph Burkart

Screw type junctional tourniquet being tightened

SOFT-W tourniquets w/ adapter strap

Screw type junctional tourniquet CAD (L), 3D printed assembly (R)

Screw type junctional tourniquet kit w/ case

MRZR Modifications & COMS Package

MTRC Engineers: Nick Sanders, Lance Shirley, Dave Macak, Nathen Storey

Who: AFSOC
What: MRZR Modification
Where: NSWC Crane
When: 08NOV17
Why: AFSOC Team required a variety of modifications to their MRZR. A mobile communication package was requested to house various electronics such as computers, phones, and antennas. This package will assist the command element with real-time bi-directional communication capabilities.

MRZR in Factory Configuration

Final Configuration after MTRC Modifications

Project Summary

- MTRC Engineers used a variety of the program's capabilities such as: Machining, Fabrication, Welding, CAD Design, and 3D printing.
- The majority of the fabrication work was made from aluminum to conserve weight while still providing necessary strength.
- A weather resistant enclosure was fabricated to house and secure all the COMS equipment and electronics.
- Two fuel can mounts, one spare tire carrier, three radio mounts, a generator platform, a rear seat adapter, and various antenna mounts were all designed, produced and mounted on the MRZR by MTRC Engineers.
- This package was completed in 6 working days.

Risk Level: Low

High side/Low side COMS Enclosure

COMS Equipment Secured in the Enclosure

Enclosure Installed in MRZR-D, with Tailgate Closed

COMS Package in Operational Status

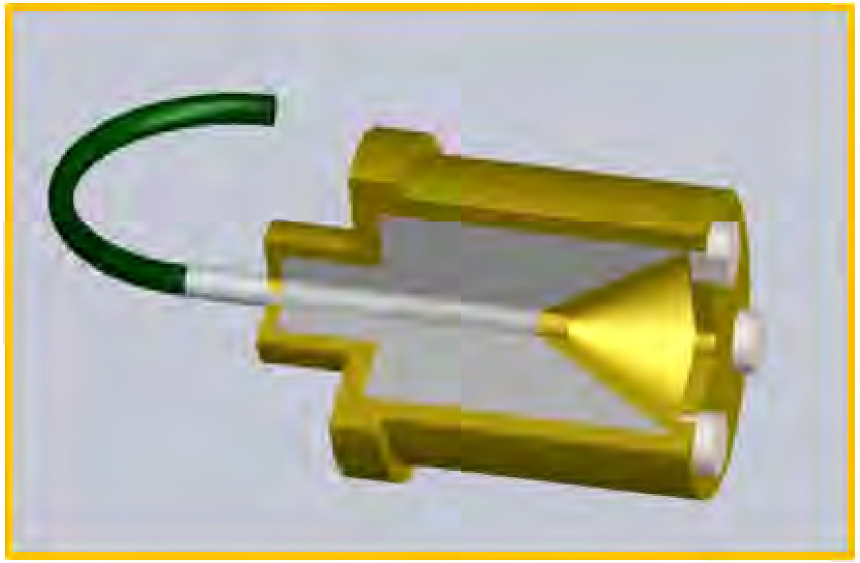
Rear of Enclosure showing Cabling Holes

Risk Level: Low

Shape Charge

Who: ODA
What: Unlined Cavity Shape Charge
Where: CP Dahlke
When: 26 FEB 2015
Why: MTRC 3D printed a 2"unlined Cavity Shape Charge to demonstrate to ODAs stationed on Camp Dahlke the ability of MTRC to assist Detachment Engineers with the production of target specific charges to exact specifications.

Charge placed on DshK using integral magnets
Charge defeated 1" hardened steel.



Engineering Method

- Using CAD MTRC designed a 2" diameter unlined cavity shape charge.
- Casing with integrated cone are 3D printed using a Makerbot Replicator.
- Three rare earth magnets are epoxied to the base to ensure quick placement on steel targets. Detachment Engineers pack the charge with C4 and seal charge with epoxy.
- End State: Detachment Engineers along with MTRC can design and build target specific charges that are easily scalable.

Risk Level: Low

Glock 17 9mm Speedloader

MTRC TM #E1: Nathen Storey

Who: 1-10 SFG(A)
What: Glock 17 Speedloader
Where: Stuttgart, Germany
When: 4JAN18
Why: 1-10 SFG(A) personnel requested Glock 17 9mm Speedloaders for quicker reloads and less abuse to fingers and gloves.


Designed in Solid Edge CAD Software and 3D Printed


Left: Original; Right: New Version

Engineering Approach

- MTRC Engineer designed the reloader in Solid Edge CAD software.
- They were printed on MTRC's FormLabs Stereolithographic Laser Printer using "Tough" Resin.
- The original variation functioned properly but a few small adjustments were made to increase ease of use and speed up reload time.

Risk Level: Negligible

Magnetic Antenna Mount

MTRC TM #E1: Nathen Storey

Who: 1-10 SFG(A)
What: Magnetic Antenna Mount
Where: Stuttgart, Germany
When: 14MAR18
Why: 1-10 SFG(A) personnel requested additional magnetic mounts for quick antenna attachment to non-standard, low-vis vehicles.

Designed in CAD and 3D Printed

Left: New design with stronger inset magnet
Right: In use on vehicle

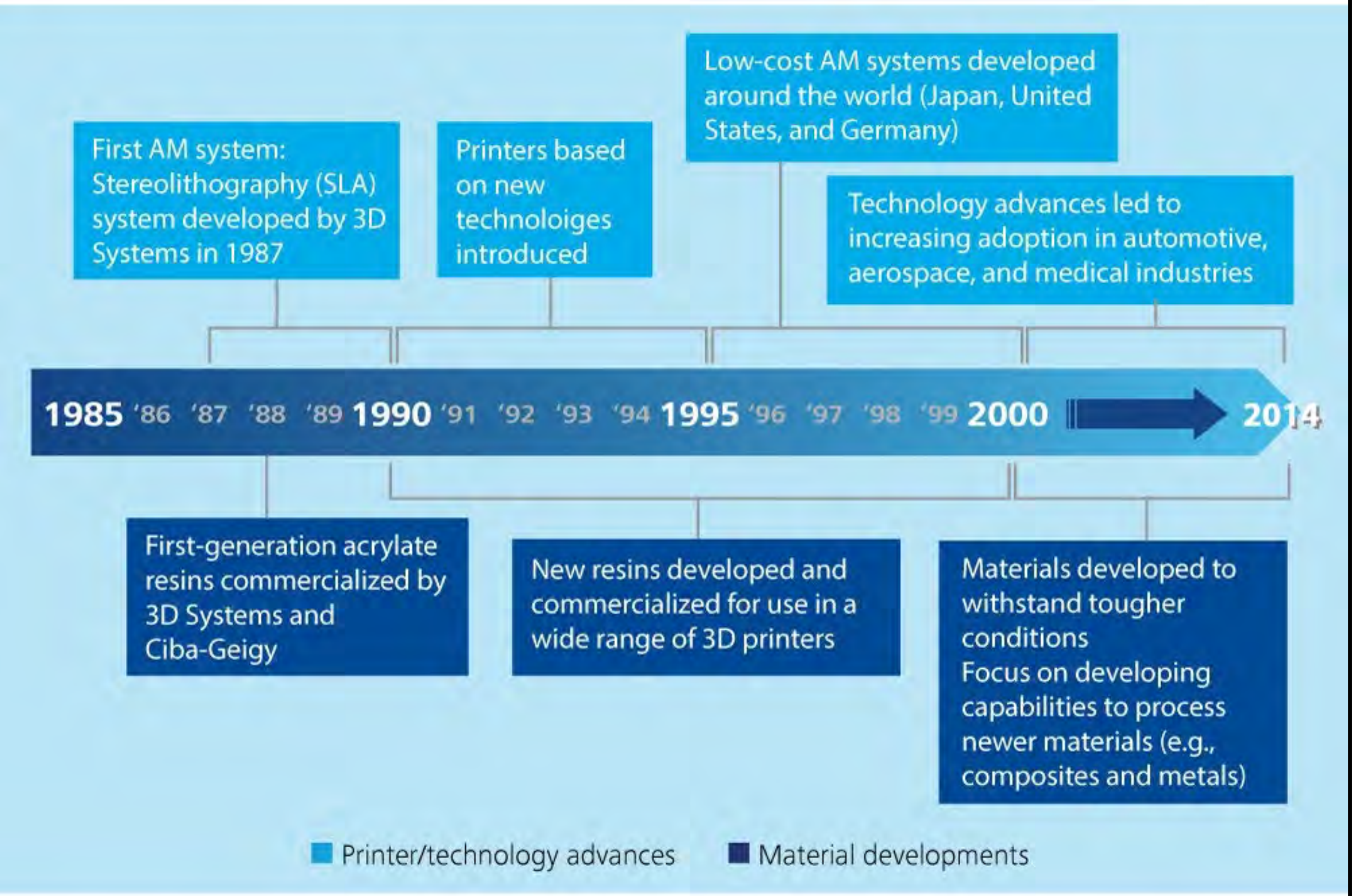
Engineering Approach

- A 90lb rated magnet was attached to base of the mount to allow for quick and secure attachment to vehicles.
- MTRC Engineer designed the mount to be lighter and lower profile than previous iterations to ensure it would remain secured to the vehicles.
- It was printed with MTRC's FormLabs Stereolithographic 3D Printer using "Tough" material for it's durability and light-weight.

Risk Level: Negligible

Additive Manufacturing History

Figure 3. Evolution of additive manufacturing technology



Source: Deloitte analysis; Wohlers Associates, *Additive manufacturing and 3D printing state of the industry*, 2012; The University of Texas at Austin, "Selective laser sintering, birth of an industry," December 7, 2012, http://www.me.utexas.edu/news/2012/0712_sls_history.php, accessed January 25, 2014.

Graphic: Deloitte University Press | DUPress.com

Additive Manufacturing Processes

Vat Photo-polymerization

Pre-deposited photopolymer selectively cured by light-activated cross linking of adjoining polymer Chains

- *Photopolymers*

Material Jetting

Droplets are selectively deposited

- *"Poly-jetting"*
- *Photopolymers*
- *Wax*
- *Sand*

Material Extrusion

Material is selectively dispensed through a nozzle/orifice in layers

- *Plastic*
- *Nylon*
- *FDM, FFF*
- *Sand*

Binder Jetting

Liquid bonding Agent selectively deposited to join powder materials

- *Metal*
- *Plastic*
- *Ceramic/Sand*
- *Full Color*

Powder Bed Fusion

Thermal energy selectively fuses regions of a powder bed

LASER & EB:
- *metals*

CO_2 LASER:
- *Polymers*
- *Fiber*

Sheet Lamination

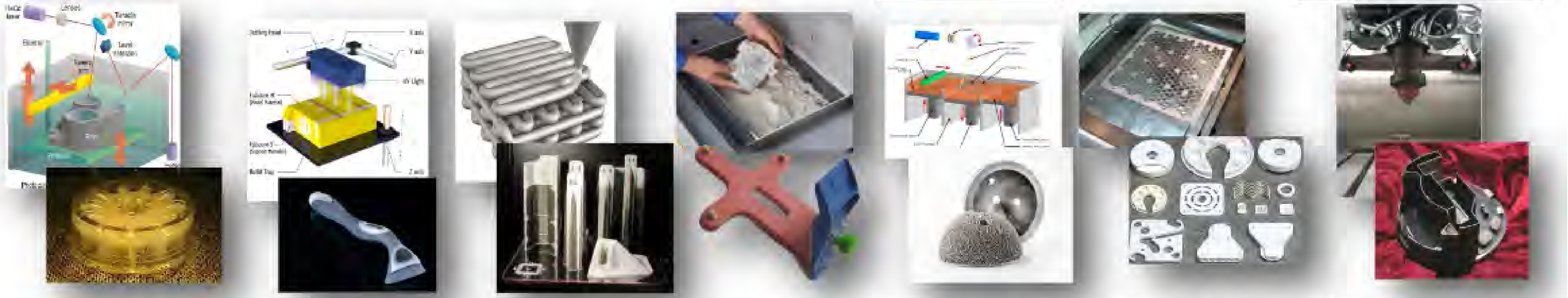
Sheets of material are bonded to form an object.

- *Metal*
- *Paper*
- *Wood*
- *Plastics*

Directed Energy Deposition

Focused thermal energy fuses materials as deposited

- *Wire & Powder*
- *LASER & EB*
- *For feature addition/repair*

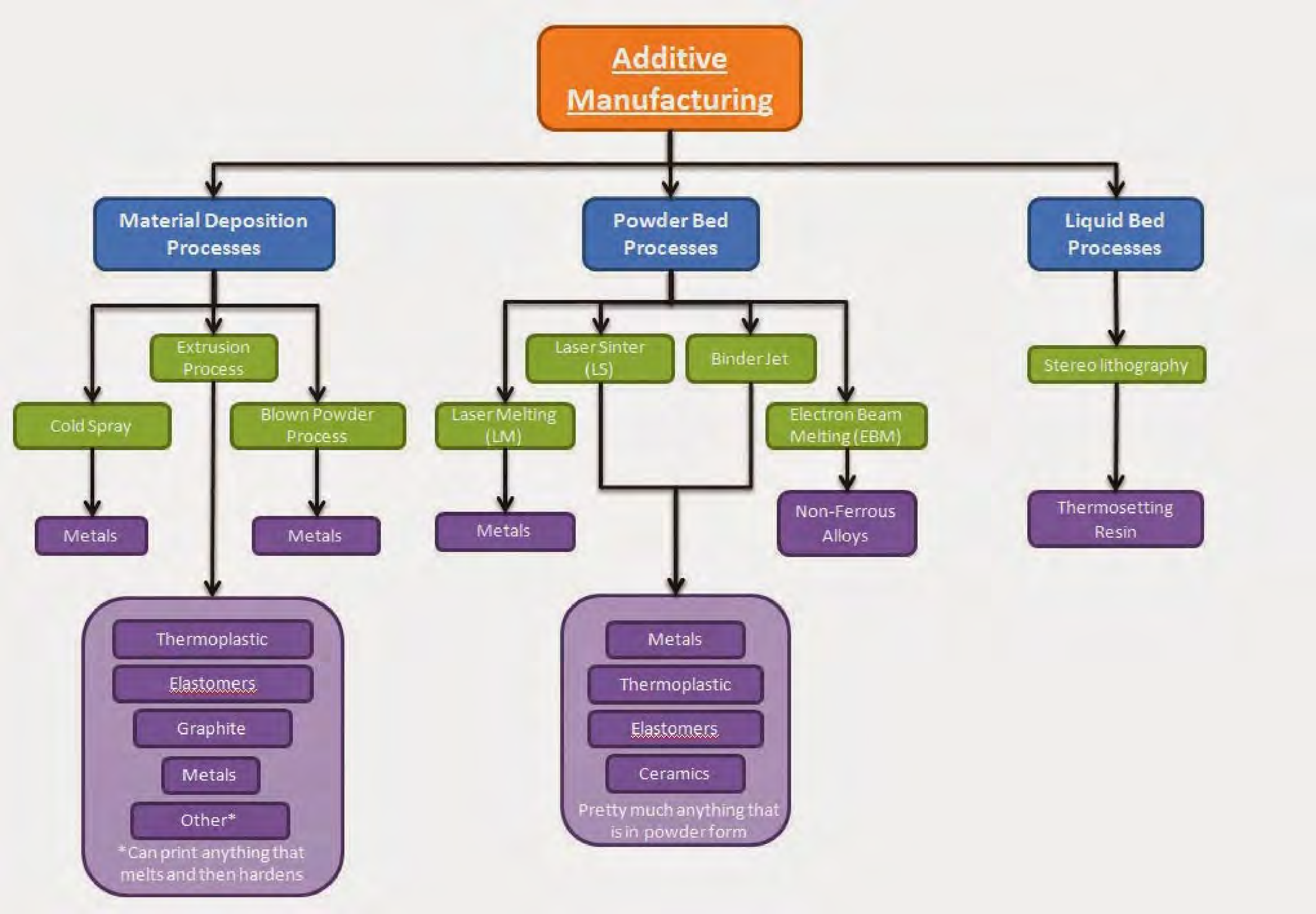


Metal Parts In-Directly (Vat Photo-polymerization, Material Jetting, Material Extrusion)

Metal Parts Directly (Binder Jetting, Powder Bed Fusion, Sheet Lamination, Directed Energy Deposition)

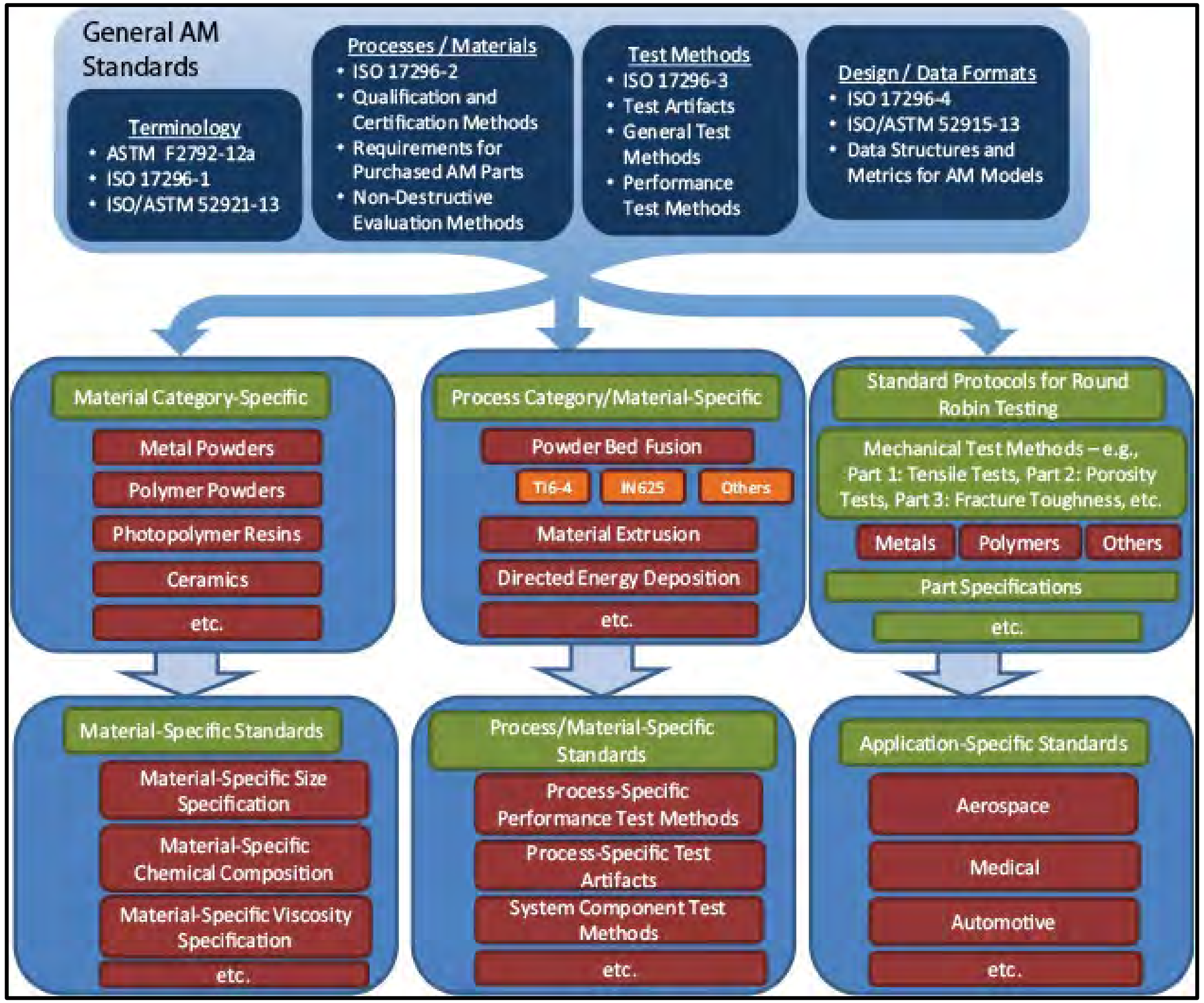
https://insights.globalspec.com/images/assets/447/7447/Seven_additive_manufacturing_processes_according_to_ASTM_Committee_F42_on_Additive_Manufacturing_Source_Boeing.png

Additive Manufacturing Materials



http://3dprintingpress.blogspot.com/2014/08/additive-manufacturing-material.html

Additive Manufacturing Standards



https://www.designworldonline.com/wp-content/uploads/2016/11/p16.jpg